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NBS
PUBLICATIONS

NBSIR 88-3748

## Center for Electronics and Electrical Engineering

# Technical Publication Announcements

Covering Center Programs,
July to September 1987,
with 1988 CEEE Events Calendar

**14**

April 1988

U.S. Department of Commerce
National Bureau of Standards
National Engineering Laboratory
Gaithersburg, Maryland 20899

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## INTRODUCTION TO THE CEEE TECHNICAL PUBLICATION ANNOUNCEMENTS

This is the fourteenth issue of a quarterly publication providing information on the technical work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Publication Announcements covers the third quarter of calendar year 1987.

Organization of Bulletin: This issue contains citations and abstracts for Center papers published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author within each topic. Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Center conferences and workshops planned for calendar year 1987, some preliminary events for 1988, and a list of sponsors of the work.

Center for Electronics and Electrical Engineering: Center programs provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards.

The metrological products of these programs aid economic growth by promoting equity and efficiency in the marketplace, by removing metrological barriers to improved productivity and innovation, by increasing U.S. competitiveness in international markets through facilitation of compliance with international agreements, and by providing technical bases for the development of voluntary standards for domestic and international trade. These metrological products also aid in the development of rational regulatory policy and promote efficient functioning of technical programs of the Government.

The work of the Center is divided into two major programs: the Semiconductor Technology Program, carried out by the Semiconductor Electronics Division in Gaithersburg, MD, and the Signals and Systems Metrology Program, carried out by the Electrosystems Division in Gaithersburg and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, CO. See the table of contents on the opposite page for identification of the topics covered by each program, as represented in this issue. Key contacts in the Center are given on the back cover; readers are encouraged to contact any of these individuals for further information.

Center sponsors: The Center Programs are sponsored by the National Bureau of Standards and a number of other organizations, in both the Federal and private sectors; these are identified on page 22.

Note on Publication Lists: Guides to earlier as well as recent work are the publication lists covering the work of each division. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 20.

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**SEMICONDUCTOR TECHNOLOGY**

Dimensional Metrology

Larrabee, R.D., **Submicrometer Optical Linewidth Metrology**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227), Vol. 775, Integrated Circuit Metrology, Inspection, and Process Control, pp. 46-50 (1987). [Conference, Santa Clara, California, March 1-6, 1987].

The National Bureau of Standards (NBS) has had a continuing program to develop optical linewidth standards for the integrated circuit industry for over 10 years. The past work has concentrated on the development and the certification of photomask linewidth and pitch standards. The recent work is directed at extending the feature sizes on these standards to cover the range from 0.5 to 30 μm, and at doubling the certification accuracy to 0.025 μm. Features with heights larger than approximately 1/4 the wavelength of the illuminating light cannot be modeled as zero-thickness layers as is done for photomasks. The development of models to handle this thick-layer case and to develop practical edge-detection criteria are currently under way at NBS. However, at the present time, it is generally not possible to interpret the image profiles of thick features and thereby measure an accurate linewidth. The basic obstacles that must be overcome to achieve accurate submicron feature size measurements for these features are reviewed, and the prospects for future NBS optical standards for features such as photoresist lines on silicon wafers are assessed. Some suggestions about what to do until these standards become available are given.
[Contact: Robert D. Larrabee, (301) 975-2298]

Nyyssonen, D., **Metrology In Microlithography**, in VLSI Electronics Microstructure Science, Microlithography for VLSI, N. G. Einspruch, ed., Chapter 7, Vol. 16, pp. 265-317 (Academic Press, 1987).

The advent of very-large-scale and very-high-speed integrated-circuit technologies has had enormous impact on the requirements for accuracy and precision of dimensional metrology. Accurate and precise measurements are needed to improve yield, to ensure that lithographic and critical dimension measurement systems meet specifications, to establish control of fabrication processes, and to relate measurements to theory or to serve as input data to modeling or simulation programs. The push to micrometer and submicrometer feature sizes on larger and larger wafers requires dimensional measurement systems with precision and accuracy which can take up only a small fraction of the error budget of 10% or less allowed in process control. By the gauge maker's rule, the measurement system tolerance must be three to ten times less than the tolerance on the part being manufactured. This book chapter discusses some of the unique requirements which metrology places on optical and scanning electron microscope measurement systems and provides a framework for realistically evaluating the capabilities of a given dimensional-measuring system in the context of the purpose for which the measurement system is to be used.
[Contact: Robert D. Larrabee, (301) 975-2298]

Nyyssonen, D., and Larrabee, R.D., **Submicrometer Linewidth Metrology in the Optical Microscope**, NBS Journal of Research, Vol. 92, No. 3, pp. 187-204 (May-June 1987).

The recent impetus of the semiconductor industry toward submicron feature sizes on integrated circuits has generated an immediate need for measurement tools and standards suitable for these features. Optical techniques have the advantages of being nondestructive and of having high throughput, but the disadvantage of using wavelengths comparable to feature size, which results in complex scattered

Dimensional Metrology (cont'd.)

fields and image structures that are difficult to interpret. Although submicron optical linewidth measurement is possible for 0.3-μm feature sizes, current instrumentation and linewidth standards, particularly for wafers, will have to improve radically in accuracy, as well as in precision, to meet the anticipated needs of the IC industry for submicron dimensional metrology. This paper discusses the effects of inadequate precision and accuracy on process control in IC fabrication and suggests some ways of circumventing these limitations until better instrumentation and standards become available.
[Contact: Robert D. Larrabee, (301) 975-2298]

Postek, M.T., **Submicrometer Dimensional Metrology in the Scanning Electron Microscope**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227), Vol. 775, Integrated Circuit Metrology, Inspection, and Process Control, pp. 166-171 (1987). [Conference, Santa Clara, California, March 1-6, 1987].

The National Bureau of Standards has initiated a program to develop scanning electron microscope linewidth measurement standards for the integrated-circuit community. This program involves the development of: a scanning electron microscope-based linewidth measurement and standard reference material certification instrument, the necessary electron beam/sample interaction modeling, and the appropriate micrometer and submicrometer artifacts. The basic problems that must be overcome to achieve accurate submicrometer feature size measurements in the scanning electron microscope for these artifacts are reviewed and some suggestions are given of what can be done to "bridge-the-gap" until such standards become available.
[Contact: Michael T. Postek, (301) 975-2299]

Packaging

Kane, D., Moore, B.A., and Walters, E.J., **RADC/NBS International Workshop on Moisture Measurement and Control for Microelectronics (IV)**, NBSIR 87-3588 (June 1987).

This fourth Workshop on Moisture Measurement and Control for Microelectronics served as a forum on moisture and/or materials reliability problems and on ways to control them or measure their extent. Twenty-two presentations are included which contain detailed information on hermeticity measurement and definition; development of standard packages for mass spectrometric calibrations; moisture interaction with various materials; and techniques that can be used to measure moisture in microelectronic packages. It was clear from several presentations in this workshop that a very systematic approach is needed when organic materials are involved; all the variables must be identified and studied one at a time. This is the key to lot-to-lot reproducibility, materials selection, and control; hence a better reliability at the design phase will decrease the need for testing, hence the cost, thus resulting in a greater satisfaction to the customer.
[Contact: E. Jane Walters, (301) 975-2050]

Integrated Circuit Test Structures

Cresswell, M.W., Pessell, N., Betsch, R.J., Linholm, L.W., and Radack, D.J., **Sub-Micron Lithography Characterization Using an Expert System**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227), Vol. 775, Integrated Circuit Metrology, Inspection, and Process Control, pp. 304-311 (1987). [Conference, Santa Clara, California, March 1-6, 1987].

This paper describes a test chip, test results, rule-generation techniques, and an expert system for characterizing the

IC Test Structures (cont'd.)

performance of a sub-micron lithography process. Examples of test results, data reduction techniques, and expert system output are given. The objective of this work is to develop a system for automatic process diagnosis.
[Contact: Loren W. Linholm, (301) 975-2052]

Radack, D.J., and Linholm, L.W., **On-Chip Propagation Delay Measurement**, Proceedings of the IEEE 1987 Custom Integrated Circuits Conference, Portland, Oregon, May 4-7, 1987, pp. 579-581.

The accurate measurement of gate propagation delay is needed for increasing the accuracy of simulators and for comparing device designs and evaluating fabrication technologies. A digital circuit is presented which can be used to determine propagation delay of any unclocked circuit element. The circuit contains on-chip logic which allows propagation delay measurement using a low-frequency parametric test system.
[Contact: Loren W. Linholm, (301) 975-2052]

Radack, D.J., Swartz, T.C., Linholm, L.W., and Cresswell, M.W., **A Comprehensive Test Chip for the Characterization of Multi-Level Interconnect Processes**, Proceedings of the 1987 IEEE VLSI Multilevel Interconnect Conference, Santa Clara, California, June 14-17, 1987, pp. 238-244 (1987).

A test chip for the evaluation and characterization of multi-level interconnect processes has been developed. The test chip contains test structures which allow a process engineer to make comparative, quantitative measurements for evaluating the performance of selected processes and equipment. This paper describes the design and testing of selected test structures and presents initial test results.
[Contact: Loren W. Linholm, (301) 975-2052]

Schafft, H.A., **Thermal Analysis of Electromigration Test Structures**, IEEE Transactions on Electron Devices, Vol. ED-34, No. 3, pp. 664-672 (March 1987).

A thermal analysis of a straight-line resistor test structure is used to show how test structure design and test conditions can affect the accuracy of electromigration characterizations of metallizations. Recommendations for the design and use of electromigration test structures are given.
[Contact: Harry A. Schafft, (301) 975-2234]

Schafft, H.A., Staton, T., Mandel, J., and Shott, J., **Reproducibility of Electromigration Measurements**, IEEE Transactions on Electron Devices, Vol. ED-34, No. 3, pp. 673-681 (March 1987).

The reproducibility of median-time-to-failure ($t_{50}$) measurements was determined in an interlaboratory experiment in which 11 laboratories and a reference laboratory took part. Each laboratory used a method of its choosing to test equivalent samples under the same conditions of current density and oven temperature. The between-laboratory reproducibility of $t_{50}$ measurements normalized to one metallization temperature was dependent on current-density stress: at 1.0 MA/cm$^2$ it was within 15%, while at 2.5 MA/cm$^2$ it was generally within 50%. The primary source for variability is in estimating the temperature rise of the test metallization due to joule heating. Recommendations are given for the design and test of electromigration test structures to improve the reproducibility of $t_{50}$ measurements.
[Contact: Harry A. Schafft, (301) 975-2234]

Device Physics and Modeling

Albers, J., **Semiconductor Measurement Technology: Results of the Monte Carlo Calculation of One- and Two-Dimensional Distributions of Particles and Damage:**

Device Physics and Modeling (cont'd.)

**Ion Implanted Dopants in Silicon**, NBS Special Publication 400-79 (September 1987).

The TRansport of Ions in Matter (TRIM) Monte Carlo code was used to calculate the two-dimensional distributions of particles, primary damage, and electronic and nuclear energy loss for implantation of a line beam source into silicon targets. Approximate two-dimensional distributions of the Frenkel pairs (vacancy-interstitial) created by the primary displacement damage of the target atoms were calculated by means of the Kinchin-Pease equation. These particle, damage, and energy loss distributions allowed for the calculation of the one-dimensional distributions of these quantities for implantation into unmasked targets. A superposition technique was used to construct the two-dimensional particle and approximate Frenkel pairs distributions for implantation past a mask edge. The energetic ions used in the calculations were in two groups: those used as intentional dopants in silicon device fabrication and those which either limited lifetime or acted as gettering sites. The particle distributions were parameterized by means of standard polynomial fitting techniques.
[Contact: John Albers, (301) 975-2075]

Bennett, H.S., **Fundamental Principles for Gallium Arsenide Devices**, Proceedings of the International Symposium on Circuits and Systems, Philadelphia, Pennsylvania, May 4-7, 1987, pp. 12-14 (1987).

Recent advances in physics for submicrometer silicon devices suggest lessons or principles that are valid when numerically simulating the behavior of GaAs devices. These lessons from physics for silicon devices are summarized and their implications for GaAs devices are given.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., **Submicron Device Physics for Numerical Simulations**, Proceedings of the SPIE (International Society of Optical Engineering, P.O. Box 10, Bellingham, WA 98227-0010), Vol. 763, Physics of Amorphous Semiconductor Devices, pp. 134-140 (1987). [Conference, Los Angeles, California, January 15-17, 1987]

Recent advances in physics for submicron, bipolar-crystalline devices suggest principles that are valid when modeling bipolar devices with noncrystalline regions such as those with polysilicon, polycrystalline silicon, and hydrogenated amorphous silicon emitters. These principles from crystalline device physics are summarized, and their implications for the noncrystalline regions of bipolar devices are given.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., and Lowney, J.R., **Models for Heavy Doping Effects in Gallium Arsenide**, Journal of Applied Physics, Vol. 62, No. 2, pp. 521-527 (July 15, 1987).

Knowledge of the parameters that describe how the band edges, densities of states, and the effective intrinsic carrier concentrations vary with dopant and carrier densities are essential for reliable predictions from numerical simulations of GaAs/AlGaAs devices and for interpreting optical measurements. Klauder's self-energy method, which is self-consistent, is used to calculate the effects due to the interactions between carriers and dopant ions in GaAs at 300 K. The many-body effects due to the interactions among the carriers themselves, exchange, and correlation are estimated by evaluating expressions similar to those of Abram et al. at 300 K. When densities exceed about $5 \times 10^{16}$ $cm^{-3}$ in n-type GaAs and $10^{18}$ $cm^{-3}$ in p-type GaAs, carrier-dopant ion interactions and carrier-carrier interactions become significant and should be included in calculations of band structure changes and of properties which depend

Device Physics and Modeling (cont'd.)

changes and of properties which depend on the density of states such as carrier transport, effective intrinsic carrier concentrations, and coefficients for optical absorption.
[Contact: Herbert S. Bennett, (301) 975-2079]

Gaitan, M., and Mayergoyz, I.D., **Time Perturbation Analysis for the MOS System**, in Fundamental Research on the Numerical Modelling of Semiconductor Devices and Processes, J.J.H. Miller, Ed., pp. 77-83 (Boole, Ireland, 1987) [Proceedings of the First International Workshop on the Numerical Modelling of Semiconductors, Los Angeles, California, December 11-12, 1986]. [Paper also appeared in COMPEL, Vol. 6, No. 22, pp. 77-83 (1987).]

The development of a numerical implementation of the small-signal response of MOS (metal oxide-semiconductor) capacitors, using time perturbation analysis is discussed. The effects of nonconstant doping profiles and interface and bulk traps are included. The model uses Fermi-Dirac statistics to describe the occupancy of the interface and bulk traps. The oxide region is considered to have no mobile carriers, and any fixed oxide charge distribution is modeled as a charge sheet at the $Si-SiO_2$ interface. This technique can be used to find the small signal response of a device from the static solution.
[Contact: Michael Gaitan, (301) 975-2070]

Hefner, A.R., and Blackburn, D.L., **A Performance Trade-Off for the Insulated Gate Bipolar Transistor: Buffer Layer Versus Base Lifetime Reduction**, IEEE Transactions on Power Electronics, Vol. PE-2, No. 3, 194-207 (1987). [Identical paper appeared in PESC '86, Proceedings of the 17th Annual IEEE Power Electronics Specialists Conference, pp. 27-38 (1986).]

A one-dimensional analytic model for the insulated gate bipolar transistor (IGBT), which includes a high-doped buffer layer in the low-doped bipolar transistor base, is developed. The model is used to perform a theoretical trade-off study between IGBTs with and without the buffer layer. The study is performed for devices of equal breakdown voltages, and the critical parameters chosen to "trade-off" are turn-off switching energy loss (related to turn-off time) and on-state voltage, both at a given current. In this model, as in reality, the two critical parameters are varied by 1) adjusting the doping concentration and thickness of a buffer layer included as part of the bipolar transistor base, 2) adjusting the lifetime in the lowly doped bipolar transistor base with no buffer layer included, or by 3) a combination of 1) and 2). The results of the model predict that for equal breakdown voltages an optimized device with a buffer layer has less switching energy loss for a given on-state voltage than an optimized device with no buffer layer.
[Contact: Allen R. Hefner, (301) 975-2071]

Lowney, J.R., and Bennett, H.S., **Limitations of Isotropic Theory of Band-Gap Narrowing in Si and GaAs Devices**, Proceedings of the 1987 IEEE Bipolar Circuits and Technology Meeting, Minneapolis, Minnesota, September 21-22, 1987, pp. 157-159 (1987).

The theory of band-gap narrowing based on uniform material is shown to be invalid for devices with very large doping gradients. Calculations also show that enhanced narrowing results from the built-in field.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Insulators and Interfaces

Carver, G.P., Novotny, D.B., and Kopanski, J.J., **An Innovative Measurement of Specific Contact Resistivity Confirms Lower Aluminum-Silicon Contact Resistance**, Proceedings of the 1987

Insulators and Interfaces (cont'd.)

IEEE VLSI Multilevel Interconnect Conference, Santa Clara, California, June 14-17, 1987, pp. 337-343 (1987).

New accurate data prove that the value of the aluminum-silicon specific contact resistivity is much smaller than the value determined previously by two-level planar contact resistor structures. The new data were obtained using an innovative method based upon small, geometrically well-defined contacts, for which the silicon spreading resistance can be calculated self-consistently. In this method, the total series resistance is measured at a contact window in an oxide layer to a silicon wafer. Unlike two-level planar structures, lateral and vertical current crowding effects in the metal layer are measured separately and are not involved directly in modeling the contact resistance. Using this new method, values of the specific contact resistivity between an aluminum alloy containing 1.5% silicon and silicon wafers were measured for p-type silicon resistivities in the range from 0.006 to 25 ohm-cm and for n-type silicon resistivities in the range from 0.0014 to 0.0026 ohm-cm. The specific contact resistivity values we obtained are about five times smaller than values reported from two-level planar structures, suggesting that aluminum may be useful for contact dimensions as small as 0.5 μm on a side. With the new results, multilevel conductor systems can be designed for optimal performance.
[Contact: Gary P. Carver, (301) 975-2091]

Other Semiconductor Metrology Topics

Bouldin, C.E., Forman, R.A., Bell, M.I., Donovan, E.P., and Hubler, G.K., **EXAFS Measurements of Ion and Implanted Amorphous Surface Layers**, Proceedings of the SPIE (International Society of Optical Engineering, P.O. Box 10, Bellingham, WA 98227-0010), Vol. 690, Optoelectronic Applied Sciences and Engineering, pp. 45-51 (1986). [Conference, San Diego, California, August 17, 1986]

EXAFS measurements of ion-damaged amorphous Ge (a-Ge) show that low-temperature annealing causes a structural relaxation in the as-implanted a-Ge. It is found that there is a sharpening of the first shell in the radial distribution but no change occurs in the first-shell distance or coordination number. No higher shells in the radial distribution are observed either before or after annealing, indicating that these shells remain highly disordered. The observed structural relaxation is an amorphous-amorphous transition; no nucleation of microcrystals takes place. EXAFS measurements are made using conversion electron detection (CEEXAFS), which is essentially total electron yield detection in ambient conditions, allowing the EXAFS measurements to be near-surface sensitive with a sampling depth of 600 to 800 Å.
[Contact: Charles E. Bouldin, (301) 975-2946]

Zaghloul, M.E., **An Overview of Testability Measures in the Design of Digital Integrated Circuits**, Semicustom Design Guide, pp. 98-108 (1987).

This paper is an overview of testability measures in the design of digital integrated circuits. Commercial testability algorithms are described and compared. Recent developments on testability measures which enhance the role of testability are discussed.
[Contact: Loren W. Linholm, (301) 975-2052]

**FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION**

Waveform Metrology

Bell, B.A., **A Report on the NBS/CEEE Survey of Electronic Measurement Needs Below 10 MHz**, Proceedings of the National Conference of Standards Laboratories, 1987 Workshop and Symposium, Denver, Colorado, July 12-16, 1987, pp.

Waveform Metrology (cont'd.)

75-1 - 75-14.

This paper describes the results of a recent survey conducted by the Electrosystems Division of the Center for Electronics and Electrical Engineering (CEEE) at the National Bureau of Standards (NBS). A summary analysis is provided of the data obtained on questions concerning (1) critical electrical quantities and associated instrumentation and devices, (2) automatic test equipment (ATE)/complex measurement systems, and (3) conducted electromagnetic interference.
[Contact: Barry A. Bell, (301) 975-2402]

Lawton, R.A., and Meyer, K., **Waveform Standards for Electrooptics: A Pulse Duration Comparison,** IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-35, No. 4, pp. 450-453 (April 1987).

A transfer standard has been developed for use in comparing the measurement capability of the Automatic Pulse Measurement System (APMS) at the National Bureau of Standards to that of recently developed electrooptic samplers. This transfer standard is a comb generator driven by a 90-MHz sine wave. Using this standard, measurements were made of the pulse waveform of a comb generator output with both the APMS and an electro-optic sampler. A comparison was then made of the pulse duration (full width at half maximum) obtained in the two waveform measurements. The result was a duration of 102 ps as measured by the APMS and 112 ps as measured by the electro-optic sampler. The signal-to-noise ratio at the comb generator input was improved over that of previous measurements, and a correction for pulse broadening was made to achieve this result. The pulse broadening was caused by the impedance mismatch between the sampler and the transmission system (50 Ω).
[Contact: Robert A. Lawton, (303) 497-3339]

Oldham, N.M., **AC Voltage and Current Measurements,** MAPAN, Journal of Metrology Society of India, Vol. 1, No. 3, pp. 17-18 (1986).

Definitions and various measurement techniques for the measurement of ac voltage and current are given.
[Contact: N. Michael Oldham, (301) 975-2408]

Oldham, N.M., Lauq, O.B., and Waltrip, B.C., **Digitally-Synthesized Power Calibration Source,** IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 341-346 (June 1987) [CPEM 86 Proceedings issue].

A digitally synthesized source of "phantom" power for calibrating electrical power and energy meters is described. Independent sources of voltage, current, and phase angle are programmable between 0 and 240 V, 0 and 5 A, and 0 and 360 deg, respectively. The accuracy of the active and reactive power is estimated to be within ±100 ppm of the full scale apparent power (volt-amperes).
[Contact: N. Michael Oldham, (301) 975-2408]

Oldham, N.M., and Parker, M.E., **NBS Calibration System for AC Voltage,** Proceedings of the 1987 National Conference of Standards Laboratories, 1987 Workshop and Symposium, Denver, Colorado, July 12-16, 1987, pp. 47-1 - 47-6.

An automatic system for calibrating high accuracy ac voltmeters and calibrators is described. The system relies on measurements using coaxial thermal voltage converters to achieve ac-voltage uncertainties of 5 to 150 ppm from 0.01-600 volts over the frequency range of 10 Hz to 1 MHz. Specialized hardware and measurement techniques make it possible to achieve these uncertainties in test periods of approximately one minute. Random errors introduced by the system are typically less than 2 ppm (one standard deviation).
[Contact: N. Michael Oldham, (301) 975-2408]

Waveform Metrology (cont'd.)

Oldham, N.M., Parker, M.E., Young, A., and Smith, A.G., **A High Accuracy, 10 Hz - 1 MHz Automatic AC Voltage Calibration System**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987, pp. 279-281 (April 1987).

An automatic system for calibrating high-accuracy ac voltmeters and calibrators is described. The system is based on traditional coaxial thermal voltage converters to provide measurement uncertainties of 5 to 20 ppm in the audio frequency range and 5 to 150 ppm over the full range from 10 Hz to 1 MHz. Specialized hardware and measurement techniques make it possible to achieve these uncertainties in test periods of approximately one minute. Random errors introduced by the system are typically less than 2 ppm (one standard deviation).
[Contact: N. Michael Oldham, (301) 975-2408]

Schoenwetter, H.K., **Design and Characterization of a Programmable Step Generator with Very Fast Settling Performance**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 428-432 (June 1987) [CPEM 86 Proceedings issue].

A pulse generator for testing the step response of waveform recorders is described. The initial and final levels of voltage steps are each programmable within the range of ±1 V for a 50-Ω termination. Voltage steps within this range settle to within ±0.2 and ±0.1 percent of full-scale range in approximately 4 and 6 ns, respectively. The 10-90 percent transition duration is approximately 1.7 ns.
[Contact: Howard K. Schoenwetter, (301) 975-2414]

Souders, T.M., and Flach, D.R., **Accurate Frequency Response Determinations from Discrete Step-Response Data**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 433-439 (June 1987) [CPEM 86 Proceedings issue].

An approach is presented for quickly obtaining the complex frequency response of a system from sampled step-response data. Digital signal processing techniques are used extensively. An analysis of errors resulting from sampling, quantization, first differencing, and record length is included.
[Contact: T. Michael Souders, (301) 975-2406]

Cryoelectronic Metrology

Hamilton, C.A., Kautz, R.L., Lloyd, F.L., Steiner, R.L., and Field, B.F., **The NBS Josephson Array Voltage Standard**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 258-261 (June 1987).

A Josephson voltage standard based on a series array of 2076 junctions is described. When irradiated with a 15-mW signal at a frequency of 96 GHz, the array produces 15,000 quantized levels between -1.5 and 1.5 V. Initial results on high-precision comparisons with a Zener reference standard are given.
[Contact: Clark A. Hamilton, (303) 497-3740 or -3988]

Kautz, R.L., **Global Stability of Phase Lock Near Chaotic Crisis in the RF-Biased Josephson Junction**, Journal of Applied Physics, Vol. 62, No. 1, pp. 198-211 (July 1, 1987).

The global stability of phase lock in the radiofrequency-biased Josephson junction is studied through digital simulations. Global stability is determined by calculating the lifetime of the phase-locked state in the presence of thermal noise. This lifetime, the mean time required for thermal noise to induce a $2\pi$ phase slip, increases exponentially with inverse temperature in the limit of low temperatures, and the low-temperature asymptote can be parameter-

Cryoelectronic Metrology (cont'd.)

ized in terms of an activation energy $\varepsilon$ and an attempt time $\tau_o$. The activation energy is a useful measure of global stability for both periodic and chaotic phase-locked states. The behavior of $\varepsilon$ and $\tau_o$ is studied over a range of critical current densities which take the system from a region of harmonic motion through a period-doubling cascade and into a region of phase-locked chaotic behavior which is ended by a chaotic crisis. At the crisis point, the activation energy goes to zero and the attempt time goes to infinity. The results are used to determine the optimum critical current density for series-array voltage standards.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

Kautz, R.L., Hamilton, C.A., and Lloyd, F.L., **Series-Array Josephson Voltage Standards**, IEEE Transactions on Magnetics, Vol. MAG-23, No. 2, pp. 883-890 (March 1987).

Series arrays typically including 1500 Josephson junctions driven at 90 GHz have been used to generate quantized reference voltages in excess of 1 V. Such standards simplify the procedure and reduce the measurement uncertainties in the calibration of electrochemical cells.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

Ono, R.H., Cromar, M.W., Kautz, R.L., Soulen, R.J., Colwell, J.H., and Fogle, W.E., **Current-Voltage Characteristics of Nanoampere Josephson Junctions**, IEEE Transactions on Magnetics, Vol. MAG-23, No. 2, pp. 1670-1673 (March 1987) [Proceedings of the 1986 Applied Superconductivity Conference, Baltimore, Maryland, Sept. 28-Oct. 3, 1986].

We have studied the current-voltage (I-V) characteristics of small-area tunnel junctions at temperatures below 1 K. The junctions were made in an edge geometry with an Nb base electrode and had areas less than 0.05 $\mu m^2$ and critical currents in the nanoampere range. Although the measured I-V characteristics resemble those of ordinary hysteretic junctions, the supposed zero-voltage portion of the curve proved to have a finite slope and to deviate from zero voltage. For these junctions, it is apparently possible for occasional $2\pi$ phase slips to occur without switching to the usual voltage state. This behavior can be explained either by macroscopic quantum tunneling or by a model in which the effective shunt conductance of the junction is frequency-dependent.
[Contact: Michael W. Cromar, (303) 497-5375]

Peterson, R.L., **Sinusoidal Response of dc SQUIDs for rf Power Measurements**, NBS Journal of Research, Vol. 92, No. 4, pp. 253-259 (July-August 1987).

Current, power, and attenuation measurements with radiofrequency Superconducting QUantum Interface Devices (SQUIDs) are based on the fact that the voltage from the microwave readout circuit can be made a nearly sinusoidal function of the magnetic flux threading the SQUID. We point out here that an asymmetric dc SQUID with sufficiently low inductance can achieve a very sinusoidal output voltage with good modulation depth. The spectral purity of the sinusoid can be substantially better than that obtained with rf SQUID systems. The purity improves with increasing asymmetry of the junction critical currents, and decreasing values of the $LI_c$ product, where L is the SQUID inductance and $I_c$ is the smaller of the critical currents. Results of several calculations are presented. Substantial improvement in SQUID methods of rf current, power, or attenuation measurement may thus be possible with use of such dc SQUIDs.
[Contact: Robert L. Peterson, (303) 497-3750 or -3227]

Zimmerman, J.E., Beall, J.A., Cromar, M.W., and Ono, R.H., **Operation of a Y-Ba-Cu-O rf-SQUID at 81 K**, Applied Physics Letters, Vol. 51, No. 8, pp.

Cryoelectronic Metrology (cont'd.)

617-618 (August 24, 1987).

An rf superconducting quantum interference device (SQUID) has been made from bulk Y-Ba-Cu-O. The device displays quantum interference effects and operates with useful signal levels up to 81 K. The SQUID is formed from a ring of Y-Ba-Cu-O which is broken in the cryogenic environment and then recontacted. Estimates of the SQUID noise performance are given.
[Contact: James A. Beall, (303) 497-5989]

Antenna Metrology

Newell, A.C., **The Effect of Random Errors in Planar Near-Field Measurements**, Proceedings of the 1986 IEEE Antenna and Propagation Society Symposium, Philadelphia, Pennsylvania, June 8-13, 1986, pp. 196-198 (1987).

Equations have previously been derived to predict the effect of systematic errors in planar near-field measurements. Similar expressions for random errors have not been generally available, although computer simulation has been used to study some specific cases. In this report, simple general expressions are derived to predict the effect of random errors that require only minimal information about the antenna and the error distributions.
[Contact: Allen C. Newell, (303) 497-3743]

Microwave & Millimeter-Wave Metrology

Daywitt, W.C., **Complex Admittance of a Lossy Coaxial Open Circuit with a Hollow Center Conductor**, Metrologia, Vol. 24, pp. 13-22 (1987).

The reflection coefficient and complex discontinuity admittance of a coaxial open circuit with a hollow center conductor are derived from fields correct to first order in the skin depth. Results show an admittance terminating the line at the plane of the discontinuity and consisting of a resistance in parallel with a capacitive reactance. The first-order fields are also used to derive equations for the characteristic admittance, series impedanc and shunt admittance of the line. These equations include terms neglected in the well-known expressions used to calculate the line parameters, enabling error limits to be assigned to the latter.
[Contact: William C. Daywitt, (303) 497-3720]

Larsen, N.T., **Microwave Power Standards**, Proceedings of the National Conference of Standards Laboratories, 1987 Workshop and Symposium, Denver, Colorado, July 12-16, 1987, pp. 34-1 - 34-7.

A general review of the history and present status of the microwave power standards in use at the National Bureau of Standards (NBS) is presented. The standards are calorimeters, and the quantity measured is "effective efficiency." The calibration services are based on these standards. The design and evaluation of these standards are discussed.
[Contact: Neil T. Larsen, (303) 497-3711]

Optical Fiber Metrology

Danielson, B.L., and Whittenberg, C.D., **Guided-Wave Reflectometry with Micrometer Resolution** [Original title: A New Method for High Resolution Reflectometry], Applied Optics, Vol. 26, No. 14, pp. 2836-2842 (July 15, 1987).

We describe a new type of optical reflectometry which is useful in testing single-mode lightguide systems. This technique uses a scanning Michelson interferometer in conjunction with a broadband illuminating source and cross-correlation detection. High resolution is achieved through the limited coherence of the backscattered radiation. With this approach it is possible to distinguish scattering centers separated

Optical Fiber Metrology (cont'd.)

by only a few micrometers. In some cases loss may be estimated for components in the transmission path of a test lightguide. The basic principles of this diagnostic technique, along with some performance characteristics, are illustrated for an all-fiber reflectometer. We also discuss several laboratory applications which serve to demonstrate the resolution capabilities of this measurement concept.
[Contact: Bruce L. Danielson, (303) 497-5620]

Electro-Optic Metrology

Day, G.W., Hale, P.D., Deeter, M., Milner, T.E., Conrad, D., and Etzel, S.M., **Limits to the Precision of Electro-Optic and Magneto-Optic Sensors**, Optical Power Line Voltage and Current Measurement Systems, Electric Power Research Institute Report EPRI EL-5431, Vol. 1 (September 1987). [Also appeared with the same title, introduction, and short abstract as NBS Technical Note 1307 (March 1987).]

This study began with a central question, "What precision can be achieved with an electro-optic voltage sensor or a magneto-optic current sensor?" The answer has been pursued in numerous ways, through an investigation of the basic properties of materials and components, both as reported in the literature and new data generated in our laboratory; through attempts to demonstrate the feasibility of overcoming certain limitations in the properties of components; through analysis of some fundamental limitations, through the proposal of new or refined designs, and through discussions with numerous other investigators.

It was concluded that ease of obtaining high precision (in a power systems context) is not included among the advantages of using optical sensors for measurement of electromagnetic quantities. The principal difficulty was that sensors have to maintain their calibration over broad temperature ranges (at least 100°C) without the possibility of temperature stabilization. Specifically, using relatively standard approaches and an appropriate definition of precision, a precision not better than about ±1 percent can be expected. Achieving that level will require wise choices of materials, components, and design, and numerous suggestions are offered.

Judgments about the commercial viability of such devices are left to those more expert in that subject. However, worst-case situations are encountered infrequently, and therefore represent pessimistic assessments of performance in real applications. Also, the other advantages of optical sensors may in some applications be dominant considerations. Safety is one example.

Using passive temperature compensation techniques may improve the precision of optical sensors by a desired order of magnitude. Several have been examined analytically, and the authors suggest that they be investigated further. Other approaches, including temperature compensation by measurement and adjustment, could be considered, but are not discussed here. The development of all-fiber or nearly all-fiber sensors could provide very simple, low-cost measurements, even if the highest precision is not achieved, and further work in this area is suggested.
[Contact: Gordon W. Day, (303) 497-5204]

Geist, J., **Photodiode Quantum Efficiency and Spectral Responsivity Self-Calibration**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987, pp. 75-79.

High-quality silicon photodiodes can be used as primary radiometric standards in the visible portion of the radiometric spectrum. The physical basis for their use as standards, and their performance in areas pertinent to their use as stan-

Electro-Optic Metrology (cont'd.)

dards, is reviewed.
[Contact: Jon Geist, (301) 975-2066]

Geist, J., **Recent Improvements in Radiometric Accuracy Based on New Detector Technology**, Remote Sensing of Environment, Vol. 22, pp. 127-129 (1987).

Until recently, the best accuracy achievable in the measurement of radiometric properties was limited by the accuracy of the ultimate radiometric standard to which the measurement could be traced. Since about 1980, however, there have been such dramatic improvements in the accuracy of detector-based standards that this is no longer the case. These new radiometric standards are briefly reviewed in this paper, with emphasis on the intercomparisons that demonstrate their accuracy.
[Contact: Jon Geist, (301) 975-2066]

Korde, R., and Geist, J., **Stable, High Quantum Efficiency, UV-Enhanced Silicon Photodiodes by Arsenic Diffusion**, Solid-State Electronics, Vol. 30, No. 1, pp. 89-92 (1987).

Very high quantum efficiency, UV-enhanced silicon photodiodes have been developed by arsenic diffusion into p-type silicon as an alternative to the inversion layer photodiodes commonly used in precise radiometric and spectroscopic measurements. The fabricated diodes had an unbiased internal quantum efficiency that was 100% from 350 to 550 nm, and that exceeded 100% at shorter wavelengths. A typical responsivity at 200 nm was 0.1 A/W. No degradation in responsivity was detected anywhere in the 200- to 1100-nm range when these devices were exposed to 20 $mW/cm^2$ of 254-nm radiation for 60 days. Thus the theoretical maximum value of internal quantum efficiency for a diffused photodiode appears to have been achieved in the UV and short wavelength visible, without compromising the diode's long-term stability. This is marked contrast to older types of diffused photodiodes, exhibited a spectral response vs. flux characteristic that changed considerably with UV exposure.
[Contact: Jon Geist, (301) 975-2066]

Peterson, R.L., **Numerical Study of Currents and Fields in a Photoconductive Detector** [previously titled "Numerical Study of Currents and Fields in a Semiconducting Optical Detector"], IEEE Journal of Quantum Electronics, Vol. QE-23, No. 7, pp. 1185-1192 (July 1987).

A numerical study of the current, field, and carrier density distributions within a photoconductive detector is presented. The photodetector, an interdigitated Schottky barrier diode, is made with metallic fingers of alternating voltage bias on a thin semiconductor layer grown on a transparent dielectric substrate. The Poisson and continuity equations for electrons and holes are treated in two dimensions. A modified successive line overrelaxation method, faster than the capacitance matrix method, is developed as the Poisson solver. A simple alternative to the Scharfetter-Gummel treatment of current density is also introduced. We investigated steady-state cases with and without optical illumination, and transient responses to picosecond optical pulses. The steady-state current shows near saturation with increasing voltage, as observed experimentally. The calculated typical response of the silicon detector to a picosecond optical pulse is a current pulse lasting on the order of 10 ps.
[Contact: Robert L. Peterson, (303) 497-3750 or -3227]

Complex Testing

Stenbakken, G.N., and Souders, T.M., **Test Point Selection and Testability Measures via QR Factorization of Linear Models**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 406-410 (June 1987). [Paper

Complex Testing (cont'd.)

given at the 29th Midwest Symposium on Circuits and Systems, Lincoln, Nebraska, August 10-12, 1986].

An efficient algorithm is presented for selecting test points for use in applications such as calibration and fault diagnosis of electronic networks. The algorithm, based on QR factorization of the circuit sensitivity matrix, minimizes the prediction or estimation errors which result from random measurement error. A definition of testability based on the concept of minimum estimation error is also introduced. Practical examples are given.
[Contact: Gerard N. Stenbakken, (301) 975-2440]

Other Fast Signal Topics

Oates, C.W., and Young, M., **Microscope Objectives, Cover Slips, and Spherical Aberration**, Applied Optics, Vol. 26, No. 11, p. 2043 (June 1, 1987).

Microscope objectives with powers of 20X and higher will display significant spherical aberration when used to examine an optical fiber without a cover slip.
[Contact: Matt Young, (303) 497-3223 or -5342]

**ELECTRICAL SYSTEMS**

Power Systems Metrology

Aschwanden, T., Van Brunt, R.J., and Bieber, M.E., **Analysis of Dielectric Strength Data for Binary Electronegative Gas Mixtures**, Proceedings of the XVIII International Conference on Phenomena in Ionized Gases, University of Wales, Swansea, United Kingdom, July 12-16, 1987, pp. 102-103.

The consistency among dielectric strength, electron swarm, and collision cross-section data for ionization, attachment, and momentum transfer have been determined for the binary gas mixtures $SF_6$/He, $SF_6$/Ne, $SF_6$/Ar, and $SF_6/CO_2$ using a theoretical approach recently developed by Van Brunt. Dielectric strength data for $SF_6$/Ar and $SF_6/CO_2$ measured by Aschwanden can be accurately described by the model calculation and exhibit a high degree of consistency with swarm and cross-section data. The model also appears to successfully describe preliminary electrical breakdown data for $SF_6$/Ne mixtures. The theoretical model fails for $SF_6$/He because it does not allow for the important effect of Penning ionization which is possible in this case.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Fitzpatrick, G.J., Forster, E.O., Hebner, Jr., R.E., and Kelley, E.F., **Prebreakdown Cathode Processes in Liquid Hydrocarbons**, IEEE Transactions on Electrical Insulation, Vol. EI-22, No. 4, pp. 453-458 (August 1987).

Measurements are presented of the initiation of prebreakdown streamers at a point cathode in liquid hydrocarbons. Using a computer implementation of the method of images, the electric field is computed for selected geometries to confirm that the field strengths in the vicinity of these streamers are probably high enough so that electron multiplication processes can occur. High-magnification photographs of streamer initiation show that the initial streamer velocity is $(2.8 \pm 0.4) \times 10^4$ cm/s in toluene.
[Contact: Robert E. Hebner, Jr., (301) 975-2403]

Hebner, Jr., R.E., **Research for Electric Energy Systems - An Annual Report**, NBSIR 87-3643 (September 1987).

This report documents the technical progress in the five investigations which make up the project "Support of Research Projects for Electrical Energy Systems," funded by the U.S. Department of Energy. To support the measurement

Power Systems Metrology (cont'd.)

of ions in the dc transmission line environment, techniques to measure ion mobility were evaluated. In addition, techniques were developed to determine the sensitivity of an AM radio to detect partial discharges in a biological exposure facility. Within the project to develop measurement techniques and obtain basic data for gaseous dielectrics, a theoretical method was developed to evaluate the consistency among electron collision, transport, and dielectric strength data for binary gas mixtures; the gas phase hydrolysis rates for $SOF_2$ and $SOF_4$ were measured; the corona discharge oxidation mechanisms were identified and the role of negative ions on the $SOF_4$ yield was determined. Progress in interfacial measurements included the optical measurement of the electric field distribution as a streamer initiates. Progress in developing measurements for nanosecond dielectrics was in the characterization of the errors in the measurement of voltage pulses using E-dot probes and the identification of the reducation of breakdown voltage in oil for faster pulses.
[Contact: Ronald H. McKnight, (301) 975-2403]

Hebner, Jr., R.E., Kelley, E.F., Fitz-Patrick, G.J., and Forster, E.O., **The Effect of Pressure on Streamer Inception and Propagation in Liquid Hydrocarbons**, Proceedings of the Ninth International Conference on Conduction and Breakdown in Dielectric Liquids, Salford, United Kingdom, July 27-31, 1987, unpaged (July 1987).

This paper shows that for pressures between 0.1 and 5.0 MPa, the structure of a streamer originating from a cathode is significantly modified while that initiating from an anode is relatively unchanged, in toluene and hexane. For cathode streamers, the inception voltage increased from 40 ± 6 kV at 0.1 MPa to 99 ± 22 kV at 5.0 MPa. For anode streamers, the inception voltage increased from 53 ± 6 kV at 0.1 MPa to 123 ± 55 kV at 5.0 MPa.
[Contact: Edward F. Kelley, (301) 975-2424]

Hillhouse, D.L., **Assessment of Future Optical Measurements of Voltage and Current in Electric Power Systems**, Optical Power Line Voltage and Current Measurement Systems; Electric Power Research Institute Report EPRI EL-5431, Vol. 2 (September 1987).

This report summarizes the results of an investigation into the technical and economic justifications for improving power system voltage and current measurements, with special emphasis on the prospects for doing this using optical technology. The investigation consisted of gathering, analyzing, and summarizing information obtained specialists in over a dozen representative major utilities, and from nearly twenty equipment manufacturers. From this and other information, an assessment of measurement needs and of the availability of the requisite technology was developed.

The report concludes that although the technical and economic arguments either for or against optical technology for power system measurements are inconclusive, there is a widespread consensus that optical technology will become incorporated into the power grid. The consensus is based on such factors as the need for more accurate metering and the increasing automation of the power grid.
[Contact: Ronald H. McKnight, (301) 975-2403]

Oldham, N.M., Laug, O.B., and Waltrip, B.C., **Digitally-Synthesized Power Calibration Source**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 341-346 (June 1987) [CPEM 86 Proceedings issue].

A digitally synthesized source of "phantom" power for calibrating electrical power and energy meters is described. Independent sources of voltage, current, and phase angle are programmable between

Power Systems Metrology (cont'd.)

0 and 240 V, 0 and 5 A, and 0 and 360 deg, respectively. The accuracy of the active and reactive power is estimated to be within ±100 ppm of the full scale apparent power (volt-amperes).
[Contact: N. Michael Oldham, (301) 975-2408]

Petersons, O., and Mehta, S.P., **An Active High Voltage Divider and Phase Shifter,** IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 362-368 (June 1987) [CPEM 86 Proceedings issue].

An instrument combining the functions of an active high voltage divider and a phase shifter designed to yield small phase-angle uncertainties within 20 μrad is described. It is based on a circuit employing a feedback amplifier and a controlled source. The presence of the controlled source greatly reduces the potential of dynamic instabilities of the feedback loop and effectively eliminates the errors associated with the finite gain of the amplifier. Design and construction details and the results of the accuracy evaluation are presented.
[Contact: Oskars Petersons, (301) 975-2400]

Sieck, L.W., and Van Brunt, R.J., **Transfer of $F^-$ in Collisions of $SF_6^-$ with Fluorinated Gases and $SO_2$ at Thermal Energies,** Proceedings of the Fifteenth International Conference on the Physics of Electronic and Atomic Collisions, Brighton, United Kingdom, July 22-28, 1987, p. 710.

Measured temperature dependences of $F^-$ transfer rates for collisions of $SF_6^-$ with $SOF_2$, $SO_2F_2$, $SOF_4$, $SO_2$, $SF_4$, and $SiF_4$ are reported. The results are used to interpret the complex anionic chemistry that occurs during electrical discharges in $SF_6$.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Superconductors

Goldfarb, R.B., Clark, A.F., Braginski, A.I., and Panson, A.J., **Evidence for Two Superconducting Components in Oxygen-Annealed Single-Phase Y-Ba-Cu-O,** Cryogenics, Vol. 27, pp. 475-480 (September 1987).

The complex susceptibility of a sintered Y-Ba-Cu-O superconductor is strongly dependent on ac field amplitude, H. Very small values of H must be used for the real part of susceptibility, $\chi'$, to reach a value corresponding to bulk diamagnetism just below the critical temperature, $T_c$. The imaginary part, $\chi''$, represents hysteresis loss in the sample. Thus, $\chi''$ versus temperature becomes positive when H exceeds the lower critical field, $H_{c1}$, of the superconductor.

Annealing the material in oxygen gives rise to two distinct components, a relatively high-$T_c$, high-$H_{c1}$ superconductor (denoted as 'G' or 'good') and a relatively low-$T_c$, low-$H_{c1}$ superconductor (denoted as 'B' or 'bad'). Curves of susceptibility versus increasing temperature reflect the dual nature of the annealed sample: $\chi'$ has an inflection at the $T_c$ of the B component and approaches zero at the $T_c$ of the G component, while $\chi''$ has a peak at each $T_c$. Both critical temperatures decrease linearly with increasing H, though at very different rates. $H_{c1}$ of the G component is considerably greater than $H_{c1}$ of the B component. The lower critical fields are linearly decreasing functions of temperature.

Two models might explain the susceptibility data. In the grain model, the G component consists of superconducting grains, and the B component is either intergranular material, unfavourably orientated anisotropic grains, or oxygen-depleted grain boundaries. In the surface model, the G component is in the interior of the sample, and the B com-

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ponent is at the sample's surface. This condition could arise if there was oxygen depletion at the surface subsequent to total enrichment during annealing.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Goldfarb, R.B., Clark, A.F., Panson, A.J., and Braginski, A.I., **AC Susceptibility Measurements Near the Critical Temperature of a Y-Ba-Cu-O Superconductor**, Proceedings of Symposium S, 1987 Materials Research Society Meeting, Anaheim, California, April 23-24, 1987, pp. 261-263.

The loss component of complex susceptibility of a Y-Ba-Cu-O superconductor near its critical temperature is strongly dependent on ac field amplitude but virtually independent of frequency. This implies that magnetic hysteresis is the major loss mechanism in these materials. The temperature at which the loss first becomes positive upon warming corresponds to an equivalence between the amplitude of the ac field and the lower critical field of the superconductor.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Moreland, J.M., **Squeezable Junctions for Electron Tunneling and Surface Electric Field Experiment**, The Physics Teacher, pp. 405-411 (October 1986).

Mechanically adjusted junctions can be used for electron tunneling or surface electric field measurements. This article conceptualized their application to semiconductors, superconductors, and surface physics of conducting materials.
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Clark, A.F., Ku, H.C., and Shelton, R.N., **Electron Tunneling Measurement of the Energy Gap in a La-Sr-Cu-O Superconductor**, Cryogenics, Vol. 27, pp. 227-228 (May 1987).

We have used the break-junction technique to determine the energy gap of lanthanum-strontium-copper-oxide, one of the new high-critical-temperature superconductors. The current-voltage characteristics demonstrated a variety of tunneling behaviours. The best characteristic indicating quasiparticle tunneling between superconducting electrodes implied an energy gap of 7.0 ± 0.1 meV. Derivatives of other characteristics showed weak structure indicating possible energy gaps up to 9 meV.
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Ekin, J.W., Goodrich, L.F., Capobianco, T.E., Clark, A.F., Kwo, J., Hong, M., and Liou, S.H., **Break-Junction Tunneling Measurements of the High-$T_c$ Superconductor $Y_1Ba_2Cu_3O_{9-\delta}$**, Physical Review B, Vol. 35, No. 16, pp. 8856-8857 (June 1, 1987).

Current-voltage tunneling characteristics in a high-critical-temperature superconducting material containing predominately $Y_1Ba_2Cu_3O_{9-\delta}$ have been measured using the break-junction technique. Sharp gap structure was observed, with the largest superconductive energy gap measured to be $\Delta = 19.5 \pm 1$ meV, assuming a superconductor-insulator-superconductor junction. This energy gap corresponds to $2\Delta/k_BT_c = 4.8$ at $T = 4$ K, for a critical temperature of 93 K (midpoint of the resistive transition).
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Clark, A.F., Goodrich, L.F., Ku, H.C., and Shelton, R.N., **Tunneling Spectroscopy of a La-Sr-Cu-O Break Junction: Evidence for Strong-Coupling Superconductivity**, Physical Review B, Vol. 35, No. 16, pp. 8711-8713 (June 1, 1987).

Detailed structure in the quasiparticle tunneling has been observed in La-Sr-Cu-O superconductive tunneling junctions using the break-junction tech-

Superconductors (cont'd.)

nique. Variability in the energy gap and associated structure in the current-voltage curves are observed indicating significant inhomogeneity in the superconducting properties. Large energy gaps (7.0 meV) and deep structure in the conductance derivative are evidence for a strong-coupling mechanism.
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Goodrich, L.F., Ekin, J.W., Capobianco, T.E., and Clark, A.F., **Electron Tunneling Measurements of High $T_c$ Compounds Using Break Junctions**, Japanese Journal of Applied Physics, Vol. 26, Supplement, No. 26-3, pp. 999-1000 (August 1987). [Proceedings of the 18th International Conference on Low Temperature Physics, Kyoto, Japan, August 10-16, 1987.]

We report on the break junction technique and its application to the high $T_c$ superconductors LaSrCuO and YBaCuO. In this technique, bulk samples are fractured and the freshly fractured surfaces adjusted to form a tunneling junction with vacuum or liquid helium as the insulating barrier. Precise mechanical adjustment permits the study of electron tunneling phenomena between pieces of a bulk superconductor. The current-voltage characteristics of these break junctions are variable, indicating sample inhomogeneity. However, some junction settings result in the more familiar quasi-particle signatures in the current-voltage characteristics. Low-leakage junctions indicate the presence of a sharp superconductive energy gap as well as large variations in junction conductance above the gap edge in both materials.
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Goodrich, L.F., Ekin, J.W., Capobianco, T.E., Clark, A.F., Braginski, A.I., and Panson, A.J., **Josephson Effect Above 77 K in a YBaCuO Break Junction**, Applied Physics Letters, Vol. 51, No. 7, pp. 540-541 (August 17, 1987).

We have observed the Josephson effect in a YBaCuO break junction. Critical currents as high as 10 mA were measured at 4 K for break junctions with a point contact within the fracture of a sample. The junction was susceptible to microwave radiation showing Shapiro steps with the ratio of V/f of 2.04 ± 0.05 μV/GHz compared to the pair tunneling value of h/2e = 2.068 μV/GHz. These steps were clearly visible in the current-voltage characteristics at temperatures up to 85 K.
[Contact: John M. Moreland, (303) 497-3641]

Magnetic Materials & Measurements

Capobianco, T.E., **A Review of Eddy Current Research at the National Bureau of Standards in Boulder, Colorado**, Proceedings of the DoD Conference on Nondestructive Evaluation, Charleston, South Carolina, October 29-31, 1985, pp. 164-173 (August 1987).

On-going research in eddy current nondestructive evaluation at the National Bureau of Standards in Boulder, Colorado, is reviewed. The most recent results and publications of experimental and theoretical studies are presented. This includes the areas of eddy current coil characterization and field mapping, experimental verification of eddy current-fatigue crack interaction, uniform field probe calibration, artifact standards, fatigue crack growth monitoring, and differential eddy current probe studies.
[Contact: Thomas E. Capobianco, (303) 497-3141]

Capobianco, T.E., and Fickett, F.R., **A Proposed Military Standard for Commercial Eddy Current Probes Based on Performance Characterization**, Proceedings of the 35th Defense Conference on Nondestructive Testing, Hill Air Force Base, Utah, October 28-30, 1986, pp. 135-141 (October 1986).

Magnetic Materials, etc. (cont'd.)

The latest results of the work being done on a draft military standard for characterizing commercial eddy current probes are reported. We discuss measurement techniques that have been evaluated for suitability as a characterization test method, such as field mapping and various electrical parameter measurements, and the reasons for selecting the method which has been incorporated in the present draft. Our conclusion is that the measurement of impedance change of a probe over a range of frequencies on two metals of different conductivities offers the best indicator of eddy current probe sensitivity and proper operating range.
[Contact: Thomas E. Capobianco, (303) 497-3141]

**ELECTROMAGNETIC INTERFERENCE**

Radiated Electromagnetic Interference

Camell, D.G., Larson, E.B., and Cruz, J.E., **NBS Calibration Procedures for Horizontal Dipole Antennas (25 to 1000 MHz)**, NBS Technical Note 1309 (April 1987).

This publication describes the theoretical basis and test procedures for horizontally polarized dipole calibrations at the National Bureau of Standards. Two different techniques and two different test sites are used. The standard antenna method uses the calculation of a field strength level, from the response of a simple half-wave dipole, to calibrate an antenna. This method is used at an open field site in the frequency range of 200 MHz to 1000 MHz. Procedures for both techniques are explained and measurement setups are illustrated. Measurement uncertainties are discussed. Sample reports are included for both methods.
[Contact: Dennis G. Camell, (303) 497-3214]

FitzGerrell, R.G., **Standard Linear Antennas, 30 MHz to 1000 MHz**, IEEE Transactions on Antennas and Propagation, Vol. AP-34, No. 12, pp. 1425-1429 (December 1986). [Proceedings of the Conference on Electromagnetic Compatibility, University of York, United Kingdom, September 28-October 2, 1986, pp. 147-153].

It is demonstrated that the insertion loss between pairs of thin, linear antennas may be calculated using fairly simple equations that are generally considered to be good engineering approximations. Although the insertion loss calculation does not involve antenna gain directly (some measurements are actually made in the near-field where gain is not defined), the result is precisely the quantity obtained using the antenna gains in Friis's transmission formula, assuming the mismatch loses are zero. Therefore, the antenna gain product is implicit in the more general insertion loss equations. The particular measurement of insertion loss used here yields a quantity called site attenuation by electromagnetic compatibility engineers. A close agreement between measured and calculated data provides confidence in the site attenuation calculations when the site is essentially perfect, and provides confidence in the gain product of the antenna pair calculated using basically the same equations as those used for insertion loss. It is assumed that one-half of the mean value of the difference between the calculated and measured data is a good estimate of individual antenna performance. For the antennas described here, this measure of performance is typically $\leq 0.05$ dB and on the outside, $\leq 0.42$ dB.
[Contact: Richard G. FitzGerrell, (303) 497-3737]

Hill, D.A., **Effect of a Thin Conducting Sheet on the Fields of a Buried Magnetic Dipole**, Electromagnetics, Volume 7, pp. 71-79 (1987).

The effect of a thin conducting sheet on the fields of a subsurface vertical magnetic dipole has been analyzed. The

Radiated EMI (cont'd.)

integral representation of the fields has been evaluated numerically, and numerical results for the vertical magnetic field above the source at the surface are presented in parametric form. It is found that the predicted fields give better agreement with previous transmission measurements than do the fields of a homogeneous half-space model.
[Contact: David A. Hill, (303) 497-3472]

Conducted Electromagnetic Interference

Bell, B.A., **A Report on the NBS/CEEE Survey of Electronic Measurement Needs Below 10 MHz**, Proceedings of the National Conference of Standards Laboratories, 1987 Workshop and Symposium, Denver, Colorado, July 12-16, 1987, pp. 75-1 - 75-14.

This paper describes the results of a recent survey conducted by the Electrosystems Division of the Center for Electronics and Electrical Engineering (CEEE) at the National Bureau of Standards (NBS). A summary analysis is provided of the data obtained on questions concerning (1) critical electrical quantities and associated instrumentation and devices, (2) automatic test equipment (ATE)/complex measurement systems, and (3) conducted electromagnetic interference.
[Contact: Barry A. Bell, (301) 975-2402]

Martzloff, F.D., and Wilson, P.F., **Fast Transient Tests - Trivial or Terminal Pursuit?**, Proceedings of the Electromagnetic Compatibility 1987, Zurich, Switzerland, March 3-5, 1987, pp. 283-288 (March 1987).

Measurements, augmented by theoretical simulation techniques, have been performed to determine the attenuation of fast transients propagating in typical indoor (conduit-enclosed) power lines. The rise time of the applied pulses ranges from 0.7 to 50 ns, including the International Electrotechnical Commission (IEC) 5/50 ns pulse recently recommended for fast transient tests. Theory and measurements confirm that pulse amplitude attenuation increases significantly for shorter pulses. For comparison and validation of the theoretical model, the IEC pulse was also applied to a conventional coaxial cable.
[Contact: Francois D. Martzloff, (301) 975-2409]

**ADDITIONAL INFORMATION**

Lists of Publications

Gibson, K.A., Page, J.M., and Miller, C.K.S., **A Bibliography of the NBS Electromagnetic Fields Division Publications**, NBSIR 85-3040 (February 1986).

This bibliography lists publications of the National Bureau of Standards' Electromagnetic Fields Division for the period from January 1984 through September 1985, with selected earlier publications from the Division's predecessor organizations.
[Contact: Kathryn A. Gibson, (303) 497-3132]

Kline, K.E., and DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications**, NBSIR 87-3074 (June 1987).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NBS in the period from January 1970 through December 1986. A few earlier references that are directly related to the present work of the Division are included.
[Contact: Kathryn E. Kline, (303) 497-3678]

Palla, J.C., and Meiselman, B., **Electrical and Electronic Metrology: A Bibliography of NBS Electrosystems Division Publications, NBS List of Publications 94** (January 1988).

List of Publications (cont'd.)

This bibliography covers publications of the Electrosystems Division, Center for Electronics and Electrical Engineering, NBS, and of its predecessor sections for the period January 1963 to January 1988. A brief description of the Division's technical program is given in the introduction.
[Contact: Jenny C. Palla, (301) 975-2220]

Walters, E.J., **Semiconductor Measurement Technology, NBS List of Publications 72,** [a bibliography of NBS publications for the years 1962-1987] (March 1988).

This bibliography contains reports of work performed at the National Bureau of Standards in the field of Semiconductor Measurement Technology in the period from 1962 through December 1987. An index by topic area and a list of authors are provided.
[Contact: E. Jane Walters, (301) 975-2050]

**1988 CEEE Calendar**

May 11-13 (Los Angeles, CA)

**Intersociety Conference on Thermal Phenomena in Fabrication and Operation of Electronic Components.** This Conference is sponsored by the Components, Hybrids, and Manufacturing Technology Society of the IEEE, in cooperation with ASME Committee K-16 on Heat Transfer and NBS. It is intended to provide an interdisciplinary forum for exploring the progress made in understanding, analyzing, and modeling thermal transport processes and thermally induced failures in the fabrication, assembly, and use of logic, memory, and data-storage systems. Major topic areas covered are 1) processing and fabrication, including state-of-the-art semiconductor crystal growing techniques; thermal stress in wafers, chips, substrates, PC boards, and joints; and encapsulant behavior with respect to solidification, outgassing, mechanical properties, and water vapor diffusion and absorption; 2) packaging technology, including means for cooling components from cryogenic to high temperatures and reliability as affected by failure mechanisms such as dopant migration and intermetallic growth; and 3) peripheral equipment, including data storage in both magnetic and optical media and thermal issues in dot-matrix and thermal printer heads. The conference is being held in conjunction with the Electronics Components Conference (May 9-11) at the same site. [Contact: Frank F. Oettinger, (301) 975-2054]

September 12-14 (San Jose, CA)

**VLSI and GaAs Chip Packaging Workshop.** This Workshop is co-sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE and NBS; attendees are expected to be knowledgeable in the field and to participate in discussions. Topic areas include: VLSI and wafer-scale package design (characterization and implementation, cost and performance-driven solutions); package thermal design (characteristics, results, and issues); package interconnection options (wire bonding, TAB, flip chip, or optical); GaAs IC packaging (high-speed packaging considerations); package electrical issues (reduction of parasitics, improvements in electrical performance, reduction in line resistance); integrating package design (from die to system, including assembly and test issues); VLSI package materials advancements; die-attach solutions for large chips; and new failure mechanisms in VLSI packaging. [Contact: George G. Harman, (301) 975-2097]

Planned

Early summer (Vail, CO)

**Combined Short Course on Optical Fiber and Laser Measurements.** [Contact: Aaron A. Sanders, (303) 497-5341]

1988 CEEE Calendar (cont'd.)

Early fall (Boulder, CO)

**Fiber Optics Symposium.** [Contact: Aaron A. Sanders, (303) 497-5341]

Late fall (Boulder, CO)

**Symposium on Optical Materials for High Power Lasers** (20th Boulder Damage Symposium). [Contact: Aaron A. Sanders, (303) 497-5341]

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**10. SUPPLEMENTARY NOTES**

All technical information included in this document has been previously approved for publication.

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

**11. ABSTRACT** *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

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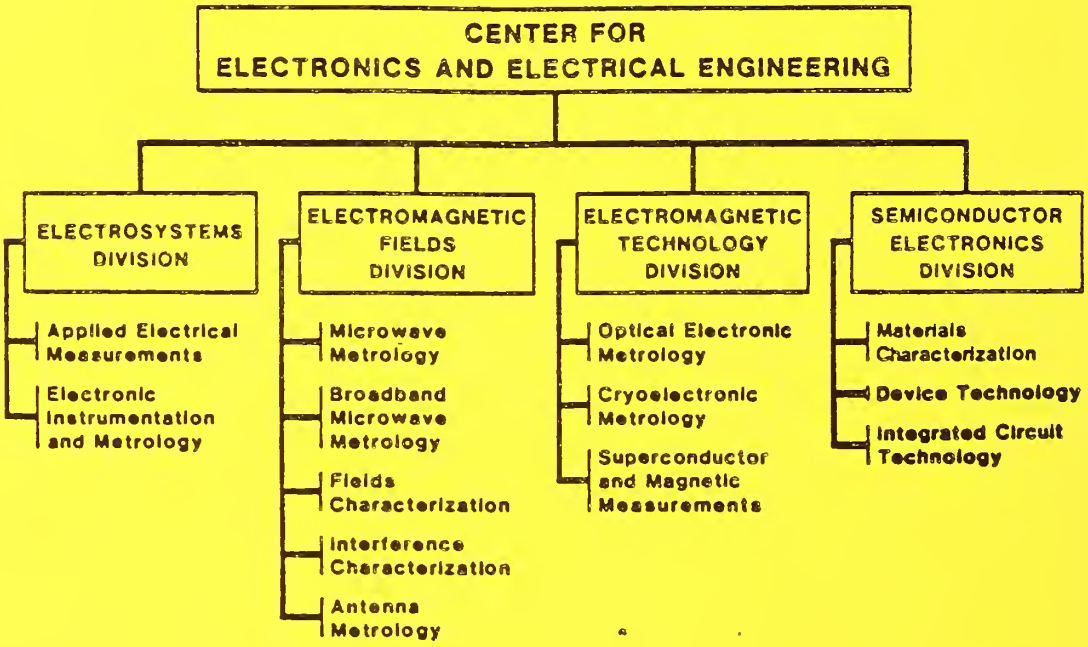


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